ENGINES RETROFIT PLAN FOR STRADDLE CARRIERS

Goal is to achieve better emission classification

Riku Puhakka

Bachelor's Thesis
June 2012
Mechanical and Production Engineering
Machine Automation

TAMPEREEN AMMATTIKORKEAKOULU
Tampere University of Applied Sciences

TIIVISTELMÄ

Tampereen ammattikorkeakoulu

Kone- ja tuotantotekniikka

Kone- ja laiteautomaatio

Riku Puhakka:

MOOTTOREIDEN JÄLKIASENNUSSUUNNITELMA KONTTILUKEILLE

Tavoite on saavuttaa parempi päästöluokitus

Opinnäytetyö 58 sivua, josta liitteitä 4 sivua

Kesäkuu 2012

Tämän opinnäytetyön tarkoitus oli selvittää teoriassa kahden erilaisen konttilukin moottorin jälkiasennus. Tavoitteena oli saavuttaa parempi päästöluokitus. Luokitukset koskevat EU:n määräämiä päästörajoja off-road laitteille ja koneille, joita käytetään yksityisillä alueilla, kuten konttien siirtoon tarvittavat laitteet. Ensimmäinen Stage luokitus implementoitiin vuonna 1999. Stage luokituksissa on viisi eri välivaihetta Stage I,II, III A, III B ja IV, neljäs on viimeinen luokitus ja tulee voimaan vuonna 2014.

Opinnäytetyössä esiteltiin aluksi yritys Cargotec Oyj. Seuraavassa vaiheessa tutkittiin, koska päästörajat ovat implementoitu, millaiset ne ovat nykyään sekä millaiset ovat tulevaisuuden näkymät. Tämän jälkeen perehdyttiin moottorin komponentteihin, joiden avulla voidaan moottorin päästöihin vaikuttaa. Myöhemmässä vaiheessa todettiin millä eri tavoin jälkiasennettuja moottoreita oli parannettu, jotta saavutettiin haluttu päästöluokitus. Teoria osuudessa perehdyttiin myös päästöjen syntymiseen sekä itse päästöihin. Eriteltyinä oli eri päästöjen syntytavat sekä ajankohdat moottorin käydessä. Säädeltyjä päästöjä oli hieman erilaisia, joten myös näihin perehdyttiin.

Viimeisessä osiossa perehdyttiin konttilukkien moottorin jälkiasennukseen sekä toimimiseen ennen voimalaitteiden muuttamista. Lisäksi selvitettiin CE–merkin merkitys sekä moottoreiden hyväksyntä prosessi. Tämän jälkeen tutkittiin itse voimalaitteiden vaihtoa. Millainen prosessi oli ja mitä osia voimalaitteiden vaihdon aikana vaihdettiin. Lopussa tehtiin yhteenveto selvitetyistä asioista.

Asiasanat: jälkiasennus, päästöluokat, päästöt

ABSTRACT

Tampereen ammattikorkeakoulu

Tampere University of Applied Sciences

Mechanical and Production Engineering

Machine Automation

Riku Puhakka:

ENGINES RETROFIT PLAN FOR STRADDLE CARRIERS

Goal is to achieve better emission classification

Bachelor's thesis 58 pages, appendices 4 pages

June 2012

Objective of this study was to clarify engine’s retrofit for two different types of straddle carriers. Purpose was to achieve better emission classification. Emission classification in Europe is called Stage classification. The first Stage I was implemented on 01.01.1999 and the last Stage IV will be launched on 01.01.2014

Study was made for Cargotec Corporation and at the beginning of this thesis reader acquainted to Cargotec Corporation. In the next phase was studied what emissions are and when emission limit was implemented at the first place, what is the situation now and what it will be in the future. After that was studied vital parts of engines, and in addition how parts influence emission limits. Furthermore was acquainted what had to been done for retrofit engines to achieve specific emission classification. In theory section was studied how different emissions are created, and in addition about emission themselves.

In the last Chapter was studied how to do the engine’s retrofit for two different straddle carriers. How to act before engine’s retrofit also was studied about a CE-marking and an official approval. Furthermore was studied how to change power units and what parts had to be changed with the power units. In the end of this thesis there was collected all necessary information into summary.

Key words: retrofit, emission classification, emissions

TABLE OF CONTENTS

1 INTRODUCTION

This bachelor’s thesis was made because it’s not a completely clear how to do an engine retrofit, when a goal is to achieve better emission classification. There are explained a few methods how to achieve smaller emission limits and what has to be done for the engines, mainly what components need to be changed. Also there are studied approval processes of the engine and EU directives. The directives are the most important due to emission limits are defined in the directives. The directives also define when every Stage standards are implemented and what is legal and what isn’t. European Union directives only effect inside European borders. There are strict limits also in United States of America but those are called Tier standards. In this study Tier standards are bypassed.

At the end of this thesis engine retrofits are studied. Answers how it’s done and what will be done after the retrofits are revealed. One significant chapter is also what parts have to be changed to be able to process the retrofit. When power units are changed it’s not clear what parts are changed and what has to be studied. For example an original generator can be different from a new generator that is meant to be in retrofit engine. Still it might be possible to use original generator.

2 CARGOTEC PRESENTATION

2.1. Introduction

Cargotec Oyj is a Finnish listed company, which supply cargo handling solutions all over the world. The biggest customers are harbours, terminals, industry, and local distribution. At the moment Cargotec has business operation and maintenance points in 160 countries. The headquarters is located in Helsinki, the chairman is Ilkka Herlin and the president and CEO is Mikael Mäkinen. The amount of employees is almost 10 000. The number of employees has been decreased due to financial depression, but it’s already back on the increase.

In 2010 Cargotec net sales were 2,6 billion EUR. From below figure 1 can be seen that the huge financial depression between years 2008-2009 also influenced to the net sales of Cargotec. Even though, the net sales didn’t decrease as much as generally. While the financial situation is getting better also the net sales are rising. The conclusion is that Cargotec is and will be also in the future one of the biggest companies in load and container handling business. The figure 2 shows how the net sales are divided by regions in year 2010. The America is the smallest area. The APAC, which stands for Asia-Pacific, and EMEA, which stands for Europe, the Middle East and Africa, are the biggest regions and also have the most potential.

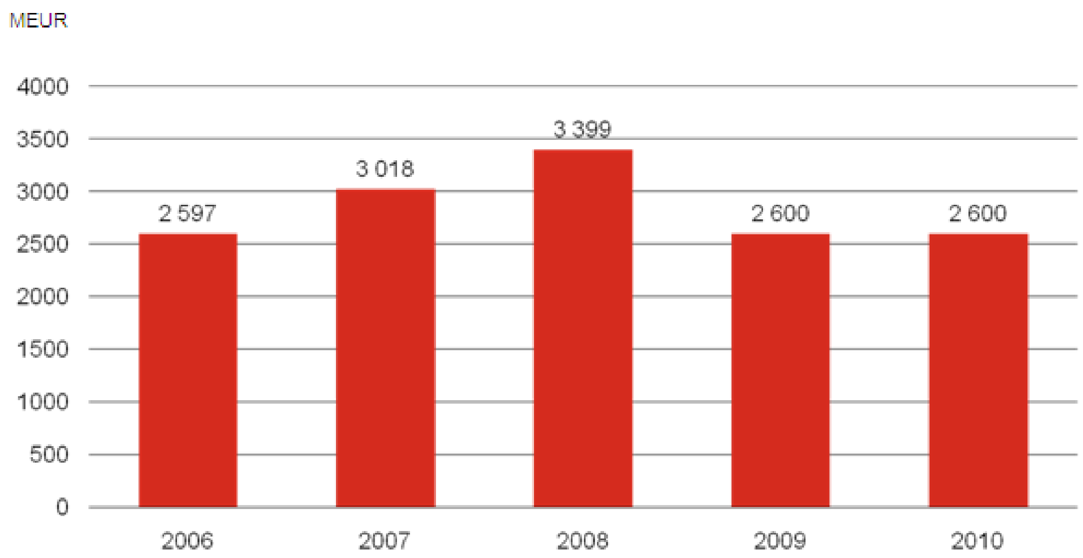

Figure 1. Net sales between 2006-2010
(Adapted from Cargotec’s internal database)

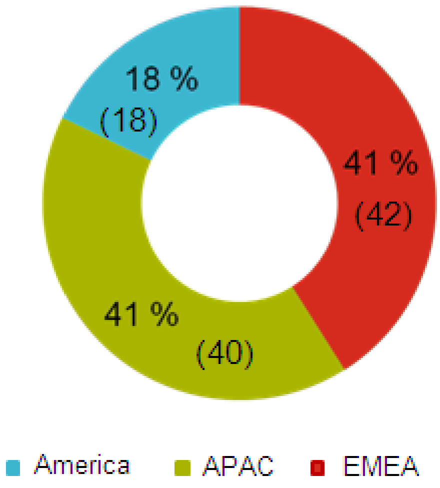

Figure 2. Net sales divided by the regions in year 2010
(Adapted from Cargotec's internal database)

2.2. History and current organization structure

To understand the current structure of Cargotec we have to go back until Cargotec was a part of Kone. Cargotec has founded in 2005 when Kone was dived to two new corporations Cargotec Oyj and Kone Oyj. At the same year Cargotec listed to Helsinki Stock Exchange. A few year earlier in 2002 Kone bought Finnish Partek, which business areas where load and container handling. Two years after Kone also bought Swedish MacGregor International AB, one of the biggest companies that offers load handling solutions for ships. Acquirement was done in order to further strengthen Cargotec's cargo handling solutions offering. The latest business event was in 2011, when Cargotec purchased a container terminal operating system manufacture Navis.

Cargotec has been divided in three different business areas Kalmar, Hiab and MacGregor, see figure 3. Also there a few other departments, which are needed to maintain the business areas. For example there are Human Resources and vacancies like Chief Operating Officer, Chief Financial Officer and Chief Technical Officer. The whole organization is shown in figure 4.

Figure 3. Business areas

(Adapted from Cargotec's internal database)

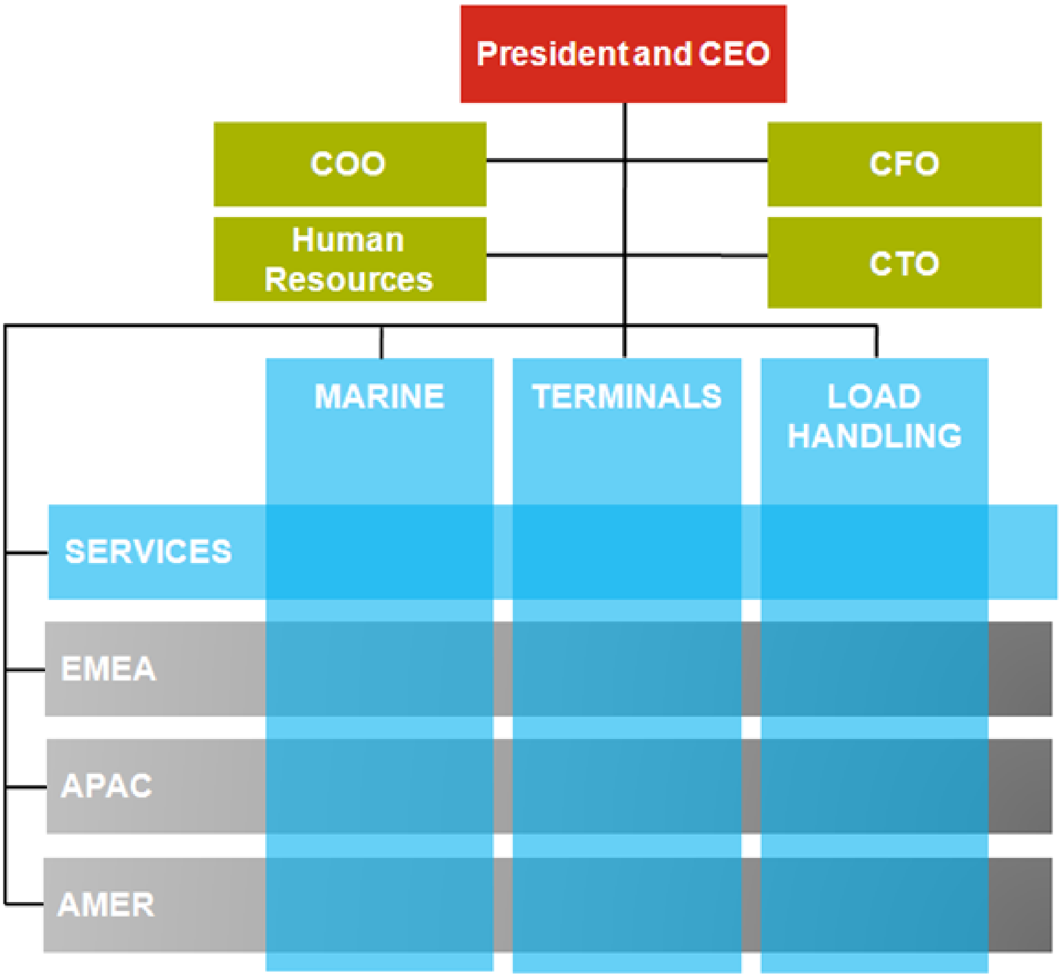

Figure 4. Organization system of Cargotec

(Adapted from Cargotec's internal database)

2.3. Kalmar, Hiab and MacGregor

Kalmar’s (Terminal) solutions are made especially for ship-to-shore and container handling. The biggest customers are ports and terminals all over the world. Terminal products and solutions are ship-to-shore cranes, straddle carriers, shuttle carriers, reach stackers, terminal tractors and of course equipment. Also Kalmar provides wide range of services, training and maintenance. Products can be seen in figure 5.

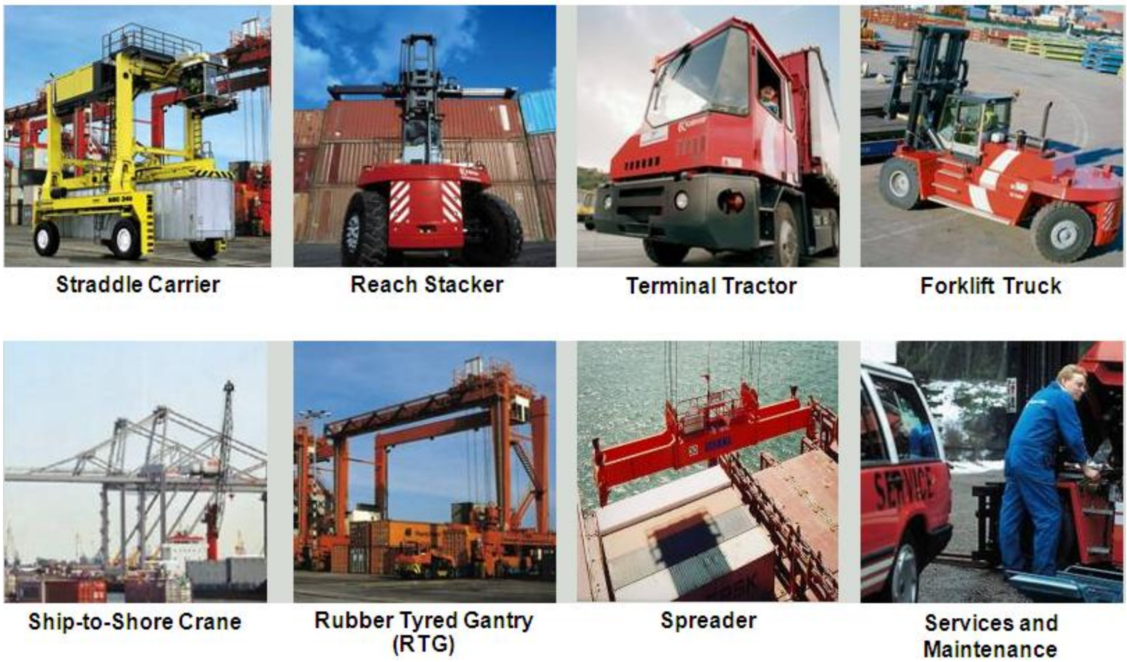

Figure 5. Wide range of Kalmar’s products
(Adapted from Cargotec’s internal database)

Hiab’s (load handling) solutions are designed for the on land transportation and delivery. The biggest customers are distribution, construction, forestry and waste and recycling corporations. Products are loader cranes, demountable trucks, forestry and recycling cranes, tail lifts and services and maintenance. Figure 6 shows the products of Hiab.

Figure 6. Wide range of Hiab’s products
(Adapted from Cargotec’s internal database)

MacGregor (Marine) provides load handling solutions at the sea. The biggest customers are ship builders, sea distribution corporations and ports. MacGregor offers for ships hatch covers, cranes, RoRo cargo and passenger access equipment, self-unloading systems, and lashing systems. For ports and terminals, MacGregor delivers linkspans, shore ramps and passenger gangways. In figure 7 can been seen some example of marine products.

Figure 7. Wide range of MacGragor’s products
(Adapted from Cargotec’s internal database)

3 GLOBAL NON-ROAD EMISSION STANDARDS

3.1. The emission standards Stage I-IV for non-road vehicles

The legislation of the European emission standards has been started on December 16th 1997. The intention was to decrease the pollution step by step to the smaller limits. As it had been impossible to implement the legislation, which would have reduced the emissions limits all at once. When emission standards are implemented, there are usually two specific dates announced, type approval date and market placement date. Type approval date means date when all newly type approved models have to fulfil the standards. Whereas market placement date means date, when all new engines placed on market have to fulfil the standards. Typically type approval date is one year before market placement date. Engine manufactures have got new emission standards usually a few years beforehand.

In the world there are a few basic standards. In Europe there is Stage classification and in USA there is Tier classification. In figure 8 there are shown worldwide emissions at regulations the moment. Tier standards Tier I, II, III, IV Interim & IV Final and Stage standards Stage II, III A, III B & IV don't have same emission values but main lines are the same. European legislation was announced to regulate emissions from off-road vehicles, which use diesel. The regulations were at the first implemented in two Stages. In year 1999 the Stage I was implemented and from year 2001 to year 2004 Stage II was implemented. Implement year depended on the power output of the engine. Below there are shown emission limits for Stage I (table 1) and Stage II (table 2), dates are market placement dates. Engine emissions are not allowed to exceed the amount shown in tables 1 and 2. Abbreviations are CO for carbon monoxide, HC for hydrocarbons, NOx for nitrogen oxides and PM is for particulate matter. The emission limits of Stage I are engine output limits and shall be achieved before any exhaust after-treatment device (www.dieselnet.com/standards 26.3.2012)

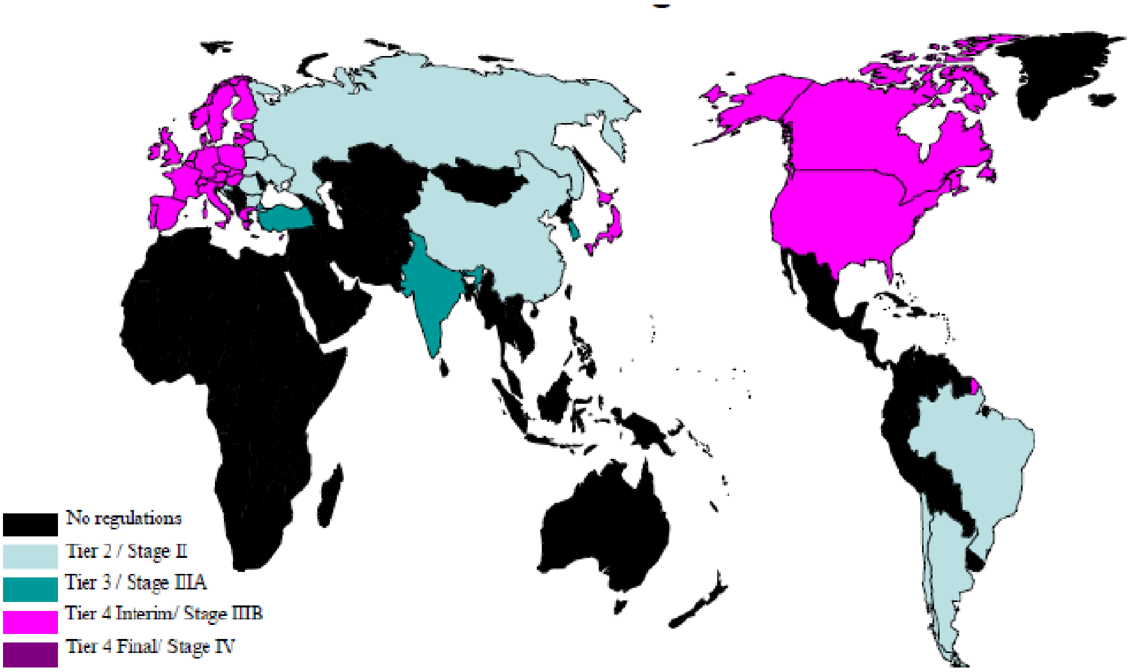

Figure 8. Worldwide emissions regulations
(Adapted from Cargotec's internal database)

Table 1. Stage I emission standards

Stage I					
Net Power [kW]	Effective Year	CO [g/kWh]	HC [g/kWh]	NOx [g/kWh]	PM [g/kWh]
130 ≤ P ≤ 560	1999	5,0	1,3	9,2	0,54
75 ≤ P < 130	1999	5,0	1,3	9,2	0,70
37 ≤ P < 75	1999	6,5	1,3	9,2	0,85

Table 2. Stage II emission standards

Stage II					
Net Power [kW]	Effective Year	CO [g/kWh]	HC [g/kWh]	Nox [g/kWh]	PM [g/kWh]
130 ≤ P ≤ 560	2002	3,5	1,0	6,0	0,2
75 ≤ P < 130	2003	5,0	1,0	6,0	0,3
37 ≤ P < 75	2004	5,0	1,3	7,0	0,4
18 ≤ P < 37	2001	5,5	1,5	8,0	0,8

In year 2004 the Stage III A, Stage III B and Stage IV were accepted by European Parliament. The Stage III A and Stage III B are and will be implemented between years 2006 and 2013. Table 3 shows Stage III A emission limits and table 4 shows Stage III B emissions limits. The implementation dates in the following tables (Table 3 - 5) refer to the market placement dates. The last Stage IV will be launched in year 2014. Stage IV emission limits shown in table 5. Stages III - IV standards there is also included a limit for ammonia emissions, which must not exceed a mean of 25 ppm over the test cycle. At the moment the Stage IV standards is the final, but in the future Stage V will be implemented during this decade.
(www.dieselnet.com/standards 26.3.2012)

Table 3. Stage III A emission standards

Stage III A				
Net Power [kW]	Effective Year	CO [g/kWh]	NOx + HC [g/kWh]	PM [g/kWh]
130 ≤ P ≤ 560	2006	3,5	4,0	0,2
75 ≤ P < 130	2007	5,0	4,0	0,3
37 ≤ P < 75	2008	5,0	4,7	0,4
19 ≤ P < 37	2007	5,5	7,5	0,6

Table 4. Stage III B emission standards

Stage III B					
Net Power [kW]	Effective Year	CO [g/kWh]	HC [g/kWh]	NOx [g/kWh]	PM [g/kWh]
130 ≤ P ≤ 560	2011	3,5	0,19	2,0	0,025
75 ≤ P < 130	2012	5,0	0,19	3,3	0,025
56 ≤ P < 75	2012	5,0	0,19	3,3	0,025
37 ≤ P < 56	2013	5,0	4,7		0,025

Table 5. Stage IV emission standards

Stage IV					
Net Power [kW]	Effective Year	CO [g/kWh]	HC [g/kWh]	NOx [g/kWh]	PM [g/kWh]
130 ≤ P ≤ 560	2014	3,5	0,19	0,4	0,025
56 ≤ P < 130	2014	5,0	0,19	0,4	0,025

As can be seen from table 4, PM emission limit where dramatically dropped in Stage III B since Stage III A. Also limit for nitrogen oxides where dropped. To achieve Stage III B new engines must be equipped with particulate filters and nitrogen oxides after-treatment devices. From beginning of Stage I limits of emission have dropped enormously. From table 6 can be seen percentage how much every emission limits have been dropped from Stage I to Stage IV. Reduction of carbon moxide has been minor but all other exhaust emissions have dropped incredible large amounts.

Table 6. Emission limit reduction percentage from stage I to stage IV

Net Power [kW]	CO [%]	HC [%]	NOx [%]	PM [%]
130 ≤ P ≤ 560	30	85,38	95,65	95,37
56 ≤ P < 130	0	85,38	95,65	96,42

3.2. Emission test cycles

Exhaust emission are tested by using test cycles. The tests are performed by the third party, which has been approved by EPA (Environmental Protection Agency) in USA or EU. The test cycles are standardized and are designed to simulate real-life operating conditions and are performed on an engine dynamometer. There are two kinds of test cycles transient cycle and steady-state cycle. In transient cycle there are accelerations, decelerations and changes in speed and load of test engine. Engine is also run double times, first with cold start and then with hot start, duration is 1200 seconds at each time. Speed and torque of the transient test are shown in figure 9. Emissions are measured either continuously through the test or through analysis of gas samples collected while testing, pollutions are expressed in g/kWh. The final emission results are weighted averages of 10% cold start and 90% hot start.

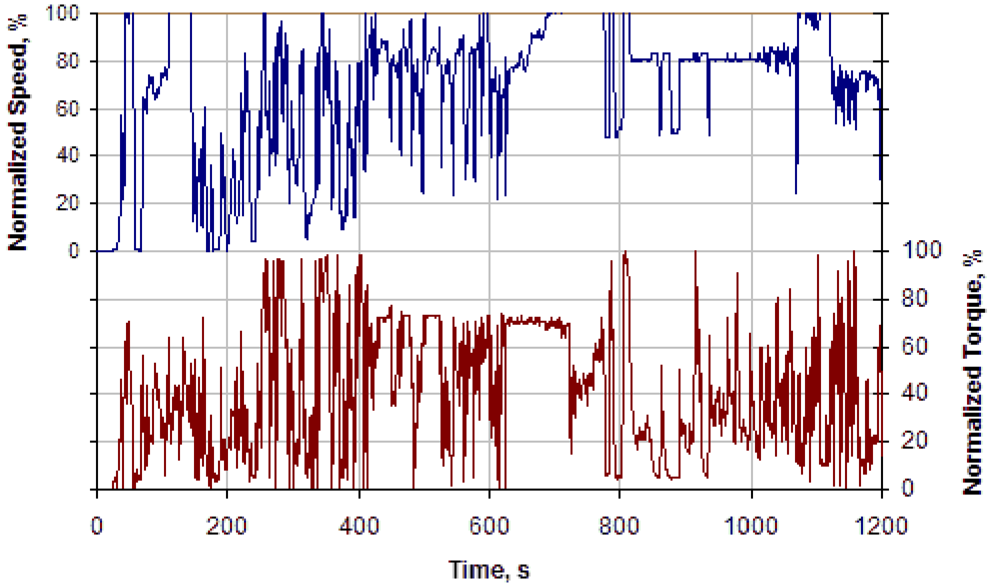

Figure 9. Speed and torque of non-road transient cycle test
(Adapted from www.dieselnet.com 26.3.2012)

In steady-state cycle engine is performed through a different speed and load modes using different weight factors. Emissions are calculated as average from each test mode. Steady-state test can be used to measure emissions for Stage I, Stage II and for Stage III A engines. Transient cycle can also used to measure emissions for Stage III A engines, if that's choice of a manufacture. Both steady-state and transient test cycles can be used to measure emissions for Stage III B and Stage IV engines.
(W. Addy Majewski and Magdi K. Khair 2006 210)
(European Union Directive 97/68/EC)

4 VITAL PARTS OF DIESEL ENGINE WHEN REDUCING EMISSIONS

4.1. Fuel injection

The fuel injection system as it name says injects fuel into the combustion chamber. At the all time it must consistently deliver exact amount of fuel to the combustion chamber. The quantity and timing of injection are controlled electronically by control unit also called ECU. The veins of the engine as it’s said, can spray fuel many times only in a part of milliseconds. The hole on top of the fuel injector unit, (see figure 10) is a size of a sharp needle and still it can spray the fuel out with pressure of around 2000 bars. The component that delivers fuel spray is called injector nozzle. The nozzle breaks the fuel into droplets of different sizes and concentrations in the spray. Atomization of fuel is needed for better injection and more perfect combustion. Fuel injection units are often driven mechanically by camshaft or rocker arm or it’s also possible to be hydraulic driven units.

Figure 10. Fuel injection unit
(Adapted from www.directindustry.com 15.3.2012)

Higher pressures of fuel injectors have led to increased the amount of injectors and have created a common rail, see figure 11. Fuel in pumped to the common rail from high pressure pump, pressure in rails can be 2000 bars. The common rail distributes fuel to all injectors and keeps the high pressure at all time, within wide operating speed range. Electronically controlled injection nozzles are connected to the rail via high pressure lines. The rail gives a command to inject fuel, and this has caused the numbers of injections to rise compared to a regular fuel pump system. Common rails are driven by the crankshaft of the engine or by electronic system. When common rails are run electronically they can be used much more the effectively. Starting and ending of spraying can be defined precisely, this makes possible to influence combustion process. Fuel is better atomized, fuel flow is faster and mixing with air is better, and all this can be easily modified by programming.
(Klaus Mollenhauer and Helmut Tschöke 2010 137-146, Richard Stone 1992 198-201)

Figure 11. Common rail
(Adapted from www.directindustry.com 15.3.2012)

4.2. Turbocharger

Turbochargers simply boost the engine by adding more air into the combustion chamber thus turbocharger increases the power output of engines. It takes the air from exhaust gas and leads the exhaust gas, which also contains small amounts of fuel, back to the combustion chamber. This exhaust gas is also pressurized in the turbocharger. Turbocharger increases the oxygen quantity in the engine and thus more fuel can be used for combustion process so the more power can be produced.

(Klaus Mollenhauer and Helmut Tschöke 2010 38-41, (Richard Stone 1992 373-275)

Inside the turbocharger, see figure 12, exhaust gases are lead through the turbine housing where it increases speed. The gas then flows through turbine wheel where it slows down again releasing energy. The turbine wheel drives a shaft that is connected to a compressor wheel. The compressor wheel draws filtered air in to the compressor housing raising both its pressure and density and forces it into the combustion chamber. (Klaus Mollenhauer and Helmut Tschöke 2010 38-41, (Richard Stone 1992 373-275))

Figure 12. Turbocharger
(Adapted from www.cummins.com 28.3.2012)

It's extremely important to use cooling for pressured air because temperature reduces the density of air. The temperature raises more at the high pressures and at the same time the temperature increases the thermal loading on the engine. For cooling, can be used an inter-cooler. It's a mechanical device that decreases the temperature of output air of turbocharger, by using outside air flow. The inter-cooler increases the air flow rate and at the same time it also reduces the air/fuel ratio. Inter-cooler is necessary for higher power outputs of engine.
(Klaus Mollenhauer and Helmut Tschöke 2010 38-41)

4.3. Intake manifold

Filtering the intake air is indeed important part of combustion process. Without filtering small particles will cause corrosion in the whole engine and reduces its life time.

Particles size for example 5-10 µm gradually rub the side of the cylinder and piston and cause small fractures. Those fractures will grow step by step and in the end the piston or cylinder has to be changed or worst the whole engine becomes useless. In addition abrasive wear caused by dust particles, can harm the walls of turbocharger and reduce the engine power output. Also filter and manifolds attenuate intake noise.

An ideal intake manifold system distributes air to all cylinders evenly without pressure lost. The combustion air is taken from the outside. The first there are prefilters to prevent the bigger particles (mainly for small stones etc.) to reach intake manifold. Inside the manifold is the main air filter, this concern almost all Cargotec's products. Manifold is usually manufactured from steel pipe and it leads air to an intake port, which is just before an intake valve and it leads intake air to the combustion chamber. The intake port is designed that the air smoothly flows in a swirl to the valve and further to the combustion chamber. Helical port, see figure 13, is designed to make the swirl, which helps mixing air and fuel at the same time maintaining good breathing quality. This process is better at the low engine speeds due to air motion. Another possible choice is to use intake port which don't have spiral in the end i.e. tangential port. It can cause more pressure but don't have swirl effect. For engine performance and formed emission, the ratio of air/fuel is critical due to that the intake manifold have to always be able to distribute air.
(W. Addy Majewski and Magdi K. Khair 2006 277-279)

Figure 13. Example of helical intake port
(Adapted from www.directindustry.com 15.3.2012)

4.4. Filters

There are three the most common types of filters dry air cleaners, oil wetted air cleaner and oil wetted air bath cleaners. Dry air cleaners are manufactured from synthetic fiber materials and cellulose, see figure 15. The special material filters extra particles from the air and leads clean air to the engine. They have a high filtration efficient, which don't depend on air flow. In generally dry air filters are installed to the place where they are easy to change, as from time to time they have to be changed. Elements have design to own high quality and excellent price/performance ratio. The principle of the dry air filter is simple. It contains a cylindrical paper element, which separate particulate matter from the air. This is possible due to vanes which make the air rotate and adds centrifugal forces in the air. Figure 14 shows the principle.

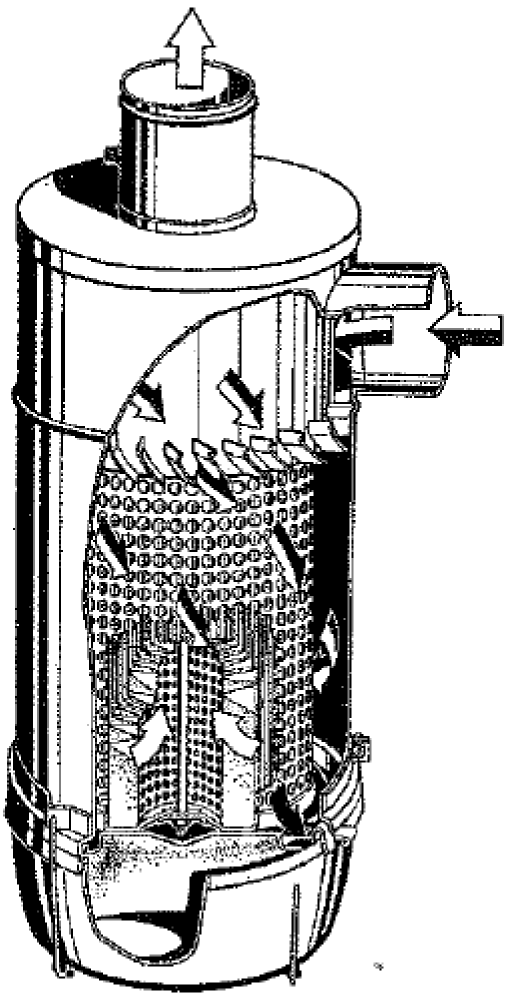

Figure 14. Dry air filter principle
(Adapted from Klaus Mollenhauer and Helmut Tschöke 2010 391)

Figure 15. Dry air filter.
(Adapted from www.cummins.com 28.3.2012)

Oil acts a major role in filtration in oil wetted air cleaner and oil wetted air bath cleaners. The air flows through central pipe into the oil bath on the bottom of the filter. The oil filters particles from air and leads the air to a special paper material filter, see figure 16. These air cleaners, which use oil in cleaning process, have lower filtration efficient than dry air cleaners. They need proper air flow and don’t work perfectly in lower air flow levels. Oil wetted air cleaners need to be cleaned from time to time, but they don’t need replacement like dry air cleaners.
(Klaus Mollenhauer and Helmut Tschöke 2010 387-393)

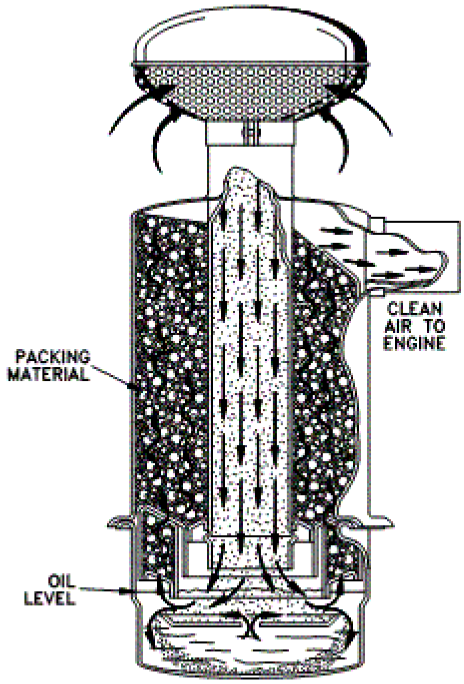

Figure 16. Oil wetted air bath cleaner
(Adapted from www.openticle.com 20.3.2012)

4.5. Exhaust gas recirculation EGR

Exhaust gas recirculation has been development to achieve smaller emission standards and at the same time it also adds engine performance. As the name says this system circulates exhaust gas. Figure 17 shows that part of a hot exhaust air is directed to the EGR. At the first it’s routed to EGR cooler to cool the exhaust gas e.g. using coolant. Cooling exhaust gas is important because this way the combustion temperature can be lowered and the NOx emission can be reduced. The next step is to flow through an EGR valve and further to an intake air manifold. The EGR valve can be controlled by air pressure or electrically. The valve adjusts coming exhaust gas depending on air pressure in intake manifold.
(W. Addy Majewski and Magdi K. Khair 2006 229-330)

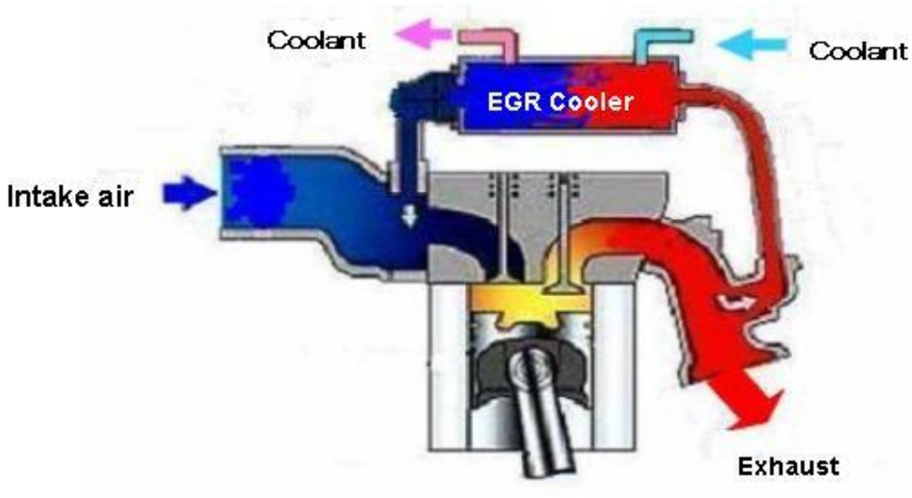

Figure 17. Principle of EGR
(Adapted from www.dailytech.com 20.3.2012)

4.5.1 EGR configurations

There are a few possible ways to improve the EGR performance in heavy-duty diesel engines. The first one is HPL which stands for high-pressure loop, see figure 18. This means that a part of exhaust gas is routed to the turbocharger where the pressure is higher than in intake manifold. Other part of exhaust gas is directed to engine cylinder via EGR valve. This system helps when the high pressure in intake and small pressure in exhaust manifold makes the exhaust gas impossible to flow to the intake manifold on its own.

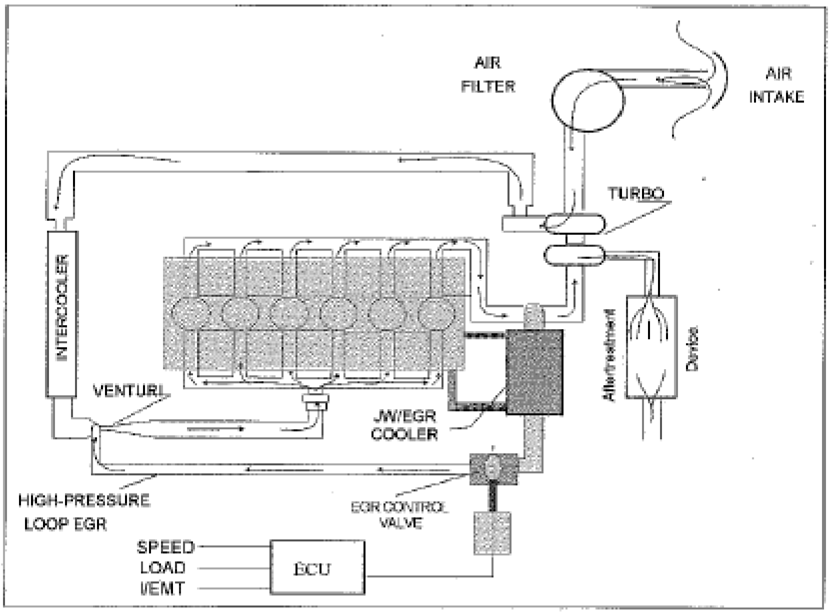

Figure 18. High-pressure loop
(Adapted from W. Addy Majewski and Magdi K. Khair 2006 331)

Another system used is LPL which stands for low-pressure loop, see figure 19. In this scheme the exhaust gas is at the first routed to the after-treatment device. There particulate matters are filtered from exhaust gas. After that the exhaust gas is recirculated to intake manifold before turbo. This is the way to improve efficient of fuel consumption due to less incombustible matter in the gas flowing to the combustion chamber. Also the gas is cooler when it’s routed to cylinders because it has flown trough intercooler.
(W. Addy Majewski and Magdi K. Khair 2006 330-332)

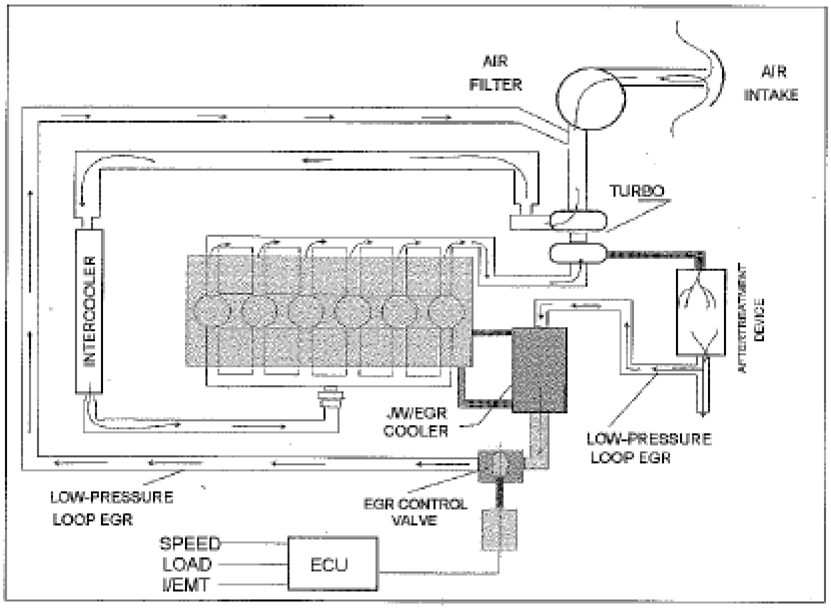

Figure 19. Low-pressure loop

(Adapted from W. Addy Majewski and Magdi K. Khair 2006 332)

4.6. Diesel oxidation catalyst DOC

Diesel oxidation catalysts (DOC, see figure 20) are converters and theirs function is to oxidize exhaust gas. Carbon monoxide and hydrocarbons are oxidized to carbon dioxide and to carbon dioxide and water. Below there are chemical formulas.

(1)

(2)

in which,

Figure 20. Diesel oxidation catalyst made by Cummins
(Adapted from www.cummins.com 10.3.2012)

The structure of diesel oxidation catalyst is usually a ceramic or metal honeycomb structure. Exhaust gas are routed into small channels app. 1 mm width. These channel's walls are made also from ceramic and metallic substrate. A washcoat, which means very thin layer of paint or sealer, and it's coating has been made of precious metals e.g. palladium and platinum. Components of exhaust gas are oxidized on this coat, while they flow through the converter. The diameter and length, density of the channels and strength of walls are the basic structural properties. These properties define mechanical stability, heating performance and exhaust back pressure.
DOC has also a few other functions, in which DOCs are efficient. For example DOC reduces particulate mass by up to 30%, when particulate matter is oxidized. Furthermore especially if used with selective catalytic reduction (SCR) DOC improves nitro dioxide ( ) to be converted to nitro monoxide ( ). Also DOC rises the temperature of the exhaust gas due to oxidising of carbon monoxide releases heat. This gives benefit for particulate filter regeneration.
(Klaus Mollenhauer and Helmut Tschöke 2010 457-458)

4.7. Diesel particulate filter DPF

Diesel particulate filters function is to separate fractions from the exhaust gas, such as particulate matter, soot, oil etc. Particles bigger than 100 nm are filtered. The efficiency of filter is app. 95%. The principle of DPF is shown in figure 21. Exhaust gas flows to the wall-flow filter. There the exhaust gas is directed in to small closed channels and furthermore through porous walls. These porous walls capture particulate matters and let clean air to pierce it. Because the particulate matter leaves inside the DPF it has to be disposed from time to time. This disposal process is called regeneration. In regeneration process soot is burned at high temperature app. over 600 °C with the oxygen contained in the exhaust gas to become carbon dioxide, incombustible filtrate constituents remaining behind as ash.

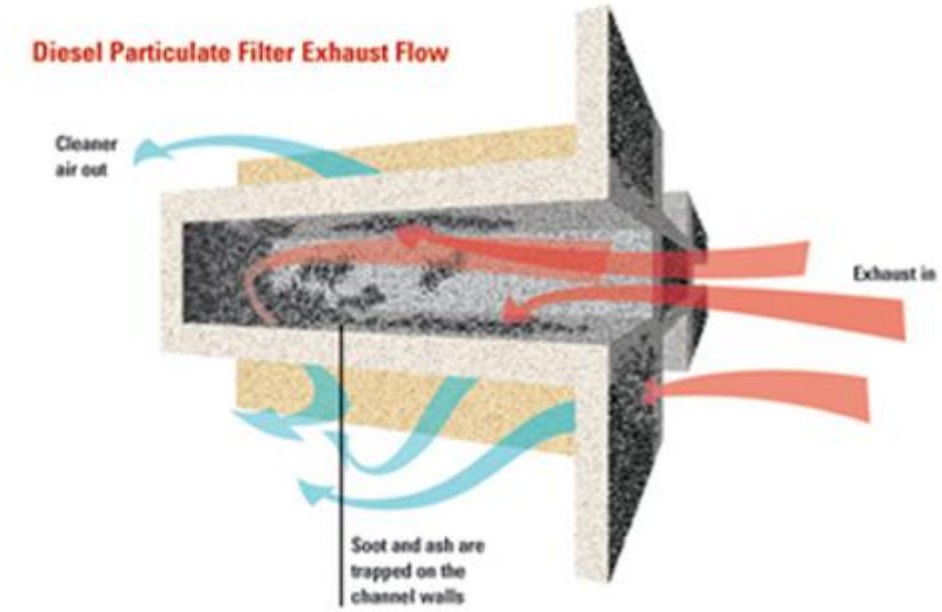

Figure 21. Diesel particulate filter exhaust flow
(Adapted from www.cummins.com 11.3.2012)

4.8. Selective catalytic reduction SCR

The function of the selective catalytic reduction is to convert nitrogen oxides (NOx) to nitrogen (   ) in a catalytic converter. Below are shown the chemical formulas of the convert process. As can be seen the ammonia is used as a reductant. Formulas 3 and 4 are the most common ones.

(3)

(4)

(5)

in which,

The optimal temperature of these reactions is between 180 °C - 450 °C otherwise the reductant doesn’t react with the oxygen involved. The process principle is to inject diesel exhaust fluid (DEF, the most common commercial brand is AdBlue) into the exhaust gas. Adblue is water based urea solution, which is non-toxic and non-hazardous. DEF is injected from its own container. The temperature of exhaust gas converts DEF to ammonia, furthermore ammonia and nitrogen oxides converts to nitrogen and water. Latter happens in the catalyst chamber. The exhaust gas is directed to round chamber, to where DEF is injected from its own container. Exhaust gas is directed to below or above a midpoint of chamber. The intention is to get a swirl flow. While the gas swirls on the walls of the chamber like a tornado, the DEF is injected into the middle of the flow. The reason is to avoid DEF touch the walls and get it mixed proper with the exhaust gas. If the DEF touches the walls of chamber, it slowly changes into the crystals and will reduce the exhaust air flow. Below figure 22 represents SCR system for Sisu 98 ATI engine. There can be seen that exhaust gas is not directed in to the midpoint of the chamber and dosing module is in the midpoint of the chamber. Catalyst chamber is shown between number threes. DEF tank and supply module are in the rear of power unit.
(Klaus Mollenhauer and Helmut Tschöke 2010 458-459)

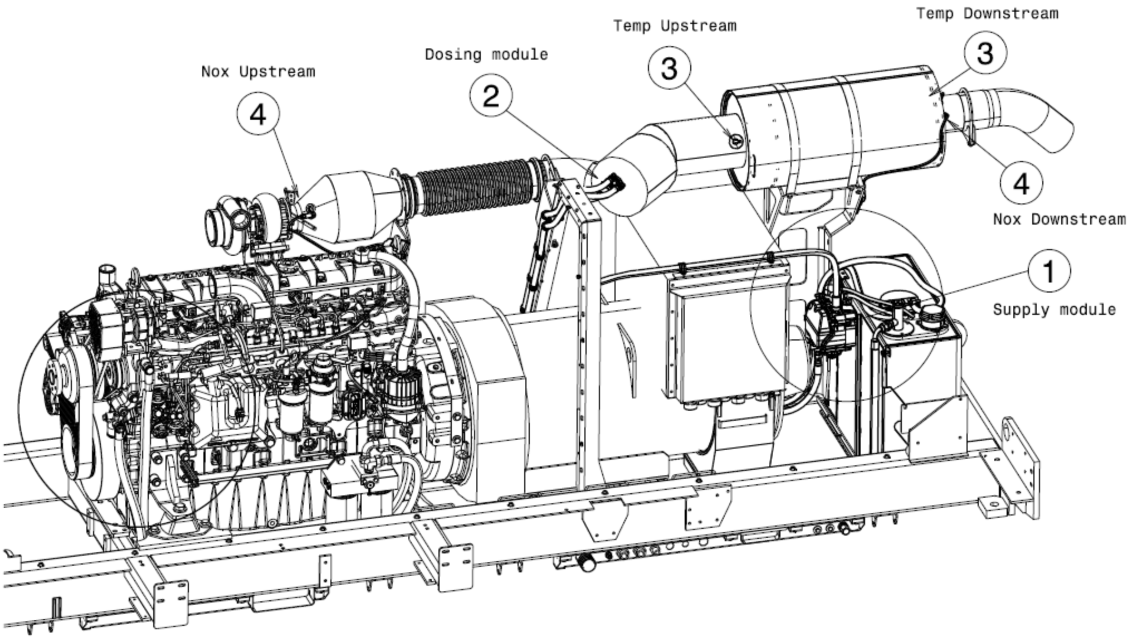

Figure 22 Selective catalytic reduction

(Adapted from Cargotec internal database)

5 DIESEL EMISSIONS

Diesel engines are internal combustion engines, so they produce emissions. The production depends on various matters, e.g. engine size, exhaust after treatment, fuel composition and fuel / air ratio. These are only a few of many factors, but all of them will cause to the emission by their own way. All that come out from the exhaust manifold are emissions. There are e.g. nitrogen, nitrogen oxides, oxygen, carbon dioxides, carbon monoxides, particulate matter, sulphur dioxides, water steam, soot and hydrocarbons. But only a few of them are paid attention in an emission control. Those are particulate matter, carbon moxides, hydrocarbons and nitrogen oxides.
(W. Addy Majewski and Magdi K. Khair 2006 445)

5.1. Particulate matter PM

Particulate matter (PM), also known as diesel particulate matter (DPM), is the black smoke coming out from the exhaust manifold, which can be seen by eyes. It consist of soot, lubricating oil, fuel, water and sulphate, percentages can be seen from figure 23. Must be understood that these percentages can vary, but the soot and lubricating oil are the biggest groups in PM. The PM is the most dangerous emission to the people, even though all the health effects are not known. The harmful effects have also lead to standardization of sampling methods. So, all laboratory tests are comparable.

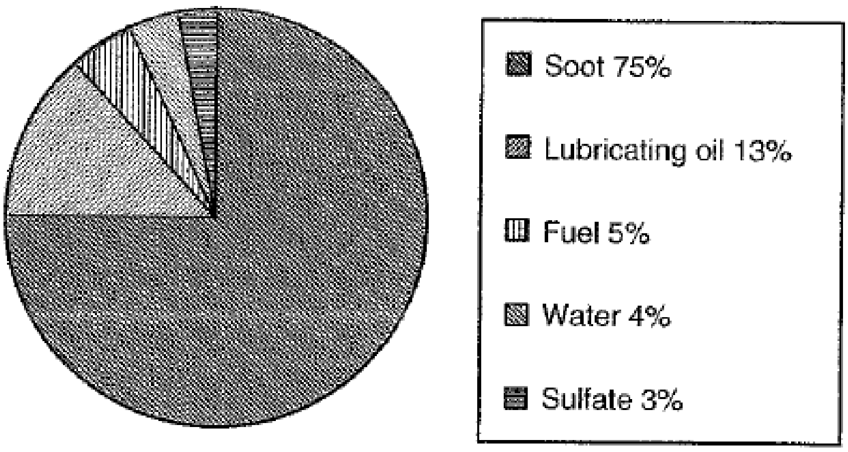

Figure 23. Consist of particulate matter
(Adapted from Klaus Mollenhauer and Helmut Tschöke 2010 446)

The particulate matter can be divided into three main fractions, solid fractions (SOL), soluble organic fractions (SOF) and sulphate particulates (SO4). Solid fractions are composed of elemental carbon, also known as inorganic carbon and ash. Carbon is formed in the combustion chamber result of heterogeneous combustion process. Metallic ash is formed from lubricating oil and wearing of engine. Ash consists of metals like calcium, zinc, and magnesium, sulphates, and oxides of iron, copper, aluminium and chromium.

Soluble organic fractions are formed of hydrocarbons adsorbed on the surface of carbon particle. These are composed of organic material derived from lubricating oil and fuel. Usually these particles vapour when they leave exhaust manifold, due to high temperatures. As in laboratory conditions soluble organic fractions are liquid in below than 52 °C temperature. The soluble organic fractions also contain the most of the polynuclear aromatic hydrocarbons, which has mutagenic and carcinogenic characters, and toxic dioxins.

Sulphate particulates are composed of sulphuric acid and water. The sulphate particulates can also consist sulphate salts, the most common is calcium sulphate. These are derived from fuel and from lubricating oil during combustion process. The most stable sulphates are formed when ratio of water and sulphuric acid is 8:3. Chemical formula is seen below.

(6)

In which

5.2. Nitrogen oxides NOx

Nitric oxides (also known as nitrogen monoxide) and nitrogen dioxides are both included in nitrogen oxides. Nitric oxide is an odourless and colourless gas which is formed in reaction of nitrogen and oxygen under high temperature and pressure. Combustion temperature influences to NOx-PM trade off. This means that when there are more nitrogen oxides developed there are less particulate matter and vice versa. Chemical reaction is seen below. Nowadays engines produce approximately 15% of nitrogen dioxides and 85% are nitric oxides.

(7)

In which

Nitrogen dioxide is a red-brown gas, it’s extremely toxic and has a tangy odour. It’s formed in a chemical reaction, which can be seen below. Nitrogen dioxide is extremely reactive and can react easily in oxidation catalyst. It’s also critical pollutant in the world. For example nitrogen dioxides can corrode skin and respiratory organs. Also it causes acid rains and eutrophication.

(8)

In which

5.3. Hydrocarbons

Hydrocarbons are organic compounds that consist of carbon and hydrogen. They can have irritating odour especially in longer carbon chains. Fossil fuels like diesel and oil are mainly composed of different kind of hydrocarbon chains. Fuels are usually shorter and lubrication oils are longer and heavier. In emission control hydrocarbons are measure either total hydrocarbons or as nonmethane hydrocarbons. From total hydrocarbons is recommended that 2 % can be subtracted. Methane is not included in emission regulation because of its different atmospheric reactivity.

5.4. Carbon monoxide

Carbon monoxide CO, also called coal gas, is a colourless and odourless gas. It’s also very flammable. Carbon monoxide burns at high temperature and can cause an increase in the gas temperature in catalytic reactors, which are designed to oxidize. Carbon monoxide is also toxic and dangerous for human beings. It replaces oxygen in bloodstream and can cause suffocation. For the earth carbon monoxide causes global warming.

6 COMBUSTION IN DIESEL ENGINE

6.1. Combustion

The first phase of combustion is a mixture preparation. Just before the highest position of piston, also known as top-dead-centre (TDC), the fuel is injected into the cylinder through injector nozzles. The fuel is injected at so high velocities that it atomizes into small droplets and reaches combustion chamber. Subsequently the fuel absorbs heat from surrounding air and vaporizes. A good atomization helps the fuel droplets to evaporate and furthermore it helps fuel mix with the air. The air has been heated and compressed earlier before it’s routed into the combustion chamber. While piston moves closer to the TDC point, the fuel-air mixture achieves fuel ignition point. The mixture ignites after ignition delay period, which is explained on the next chapter, and it is considered to start the combustion process. The auto ignition starts at numerous locations in cylinder at the same time. After the ignition the pressure in the cylinder raises and it compresses the unburned portion of the charge and shortens its delay before its ignition. Same time pressure increase also speeds up the evaporation rate of remaining fuel. In a perfect combustion all the atomization, vaporization and mixing of fuel and air continues until all fuel is combusted. Finally the products of combustions are directed out of the cylinder to the exhaust manifold.
(W. Addy Majewski and Magdi K. Khair 2006 93-94)

6.1.1 Ignition delay

Ignition delay is a time between fuel injection and ignition process. It has effect on exhaust emissions, combustion process, mechanical stress and engine noise. As already said the ignition starts at numerous locations at the same time. So it is extremely important that fuel has time to spread into the combustion chamber. At the same time it’s spread it also has time to evaporate and mix with air to form combustible mixture. Also there are chemical processes, which are occurred during ignition delay. I.e. preflame oxidation of premixed fuel and localized ignition, which occurs in several areas in the cylinder. Furthermore localized ignition leads to decomposition of heavy hydrocarbons into lighter components and formation of combustion radicals. In addition it leads to preignition chemical reactions between decomposed components and oxygen. (W. Addy Majewski and Magdi K. Khair 2006 100-101)

6.1.2 Nitrogen oxides formation in lean flame region

To understand how nitrogen oxides are formed in combustion process, we have to take a look how the ignition happens. When the fuel is sprayed into the cylinder it atomizes and forms a mixture with the air. The A/F ratio is the highest along the centreline of the spray and decreases on the edge of spray cone. In figure 24 can be seen schematic of fuel spray while it’s mixing with air. Ignition nuclei are formed at numerous locations before the ignition, and these locations will most likely auto ignite. When ignition starts independent flame fronts spreads from ignition nuclei and ignites lean mixture around them. These regions are also known as lean flame regions. There the nitrogen oxides are formed from rich fuel mixtures at high temperatures. The temperature of lean zone is the major factor to affect formation of nitrogen oxides.
(W. Addy Majewski and Magdi K. Khair 2006 94-95)

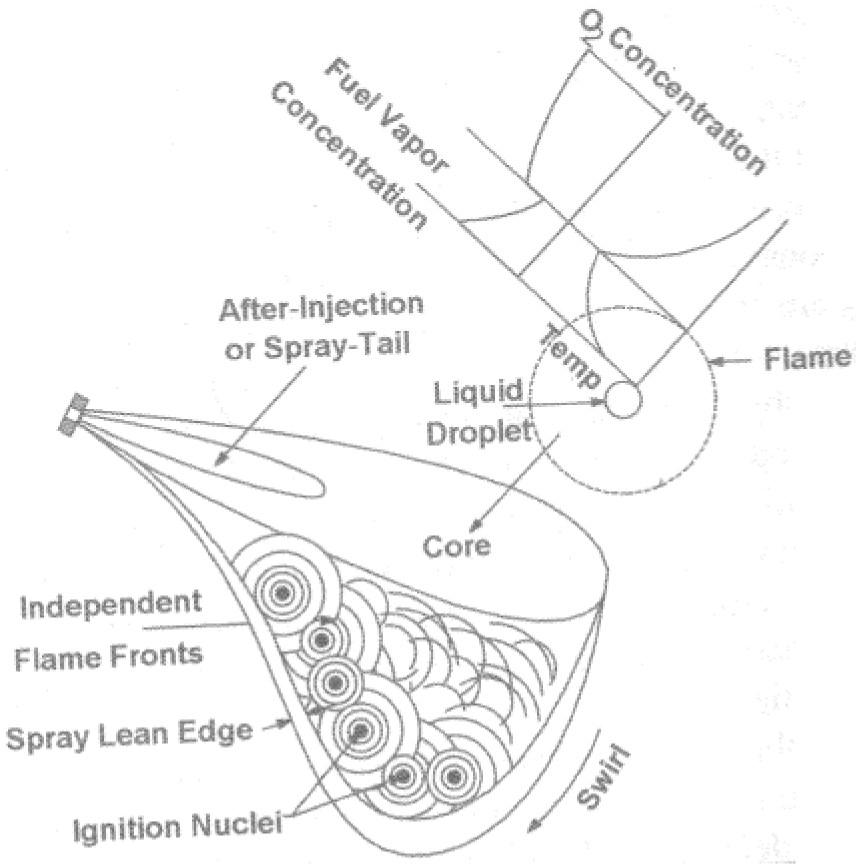

Figure 24. Schematic of a fuel spary mixing with air.
(Adapted from W. Addy Majewski and Magdi K. Khair 2006 94)

6.1.3 Hydrocarbon and carbon monoxide formation in lean frame-out region on the wall and in spray tail

Unburned hydrocarbons are formed in lean frame-out region (LFOR). It is region near of the outer edge of the spray, where the mixture is commonly too lean and due to that don’t ignite easily and combustion is usually unstable. All, air swirl, temperature and pressure in cylinder influences the size of the lean frame-out region. High pressure and temperature reduces region size due to these extend the flames to leaner mixtures and the combustion is more perfect. Hydrocarbons can also be formed on the walls of cylinder where is low oxygen concentration and combustion in more incomplete. Unburned fuel evaporates and contains unburned hydrocarbons and carbon monoxides.

In the last part spray tail fuel consist of large droplets due to smaller pressure near the end of injection process. Penetration of this part is weak and thus spray tail has a small chance to enter areas with high oxygen concentration. Due to high temperature of surrounding gases droplets evaporate quickly. Also these evaporated products contain unburned hydrocarbons, carbon monoxides and carbon molecules. The conclusion is that hydrocarbons and carbon monoxides are formed and light loads and when the combustion process is incomplete.

(W. Addy Majewski and Magdi K. Khair 2006 94-96)

7 ENGINES RETROFIT

7.1. Planning Retrofit

In the beginning of this project there were two machines to where plans of the engines retrofit packages in theory needed to be done. Machines chosen were examples, in every machine there are differences thus different matters have to be checked. In addition structures of newer machines are built differently than the old ones. This thesis gives the guidelines what have to be inspected. The two chosen machines were Container Straddle Carrier also known as CSC and Electric Straddle Carrier also known as ESC. Three main differences can be found between these two models. In CSC there are two engines located on the side frames of the machine. The engines give power directly to drive shafts, of course through transmissions. In ESC there is only one engine and it's located on top of the machine. The engine power output is attached to electric generator, which gives power to electric motors, which rotates wheels. To achieve smaller costs while planning retrofit, all originals parts had to be inspected. An idea was to be able to use original parts in a new power unit with a new engine. All parts that haven't been changed in a while or have been eroded are suggested to be changed. It has to be remembered that the final price always is the most significant matter for customers and more original parts used the smaller the final price would be. Prices of the parts are not shown in this thesis due to business secret.

At the first purpose was to install Stage III B engines for CSC and ESC machines. Unfortunately it was impossible to replace Sisu 74 ETA engine with Stage III B engine. Stage III B engine would have needed an official approval. Approval procedure would have taken something between 6 – 12 months. Due to launching of Stage IV in year 2014 the Stage III B power unit for CSC machines won't be designed not even for a production of new machines. In next chapter approval procedure is explained more specific.

After discussed with R&D engineer, was decided that for CSC machine replacement engine type will be Sisu 74 CTA Stage III A engine. From table 7 can be seen machines details and retrofit engines. In brackets there are Stage classifications of the engine, for example Sisu 74 ETA engine has Stage II engine and it complies Stage II emissions standards. The reference machine means machine which already had a new engine type installed. The reference machine is on hands of one of our customers. The reference machine helps planning a new engine retrofit as it can be used as a model. The drawing number is a number, which every machine made by Cargotec has. With the drawing number all parts included in the specific machine can be found.

Table 7. Machine details

Machine type:	CSC 350	ESC 340W
Original engine:	Sisu 74 ETA (Stage II)	Scania DC12 52A (Stage II)
Head drawing number:	N5879170	NP642000
Reference machine's head drawing number:	NP649600	NP654700
Retrofit engine:	Sisu 74 CTA (Stage III A)	Sisu 98 ATI 4V (Stage III B)

7.2. EU–directive

EU-directive is a legislative act of European Union. It doesn't change the law of member states but gives national legislators directives how to modify current laws or how to implement new ones. Every member state can choose the way to achieve directives as long as they are able to achieve whatever is instructed by European Union. All directives are given by European Parliament or Council of the European Union.

Directive 97/68/EC of the European Parliament and of the Council of 16 December 1997 is the first and original directive against non-road emission of gaseous and particulate pollutants from internal combustion engines. "This directive aims at approximating the laws of the Member States relating to emission standards and type-approval procedures for engines to be installed in non-road mobile machinery. It will contribute to the smooth function of the internal market, while protecting human health and the environment"
(European Union Directive 97/68/EC)

Directive 97/68/EC is amended by directive 2004/26/EC of the European Parliament and of the Council of 21 April 2004. There are plenty of interpolations and amendments. One that concerns retrofitting is amendment seven (7). It amends original article 10 of directive 97/68/EC. "Without prejudice to Article 7a and to Article 9(3g) and (3h), replacement engines, except for railcar, locomotive and inland waterway vessel propulsion engines, shall comply with the limit values that the engine to be replaced had to meet when originally place on the market. The text "REPLACEMENT ENGINE" shall be attached to a label on the engine or inserted into the owner's manual". This amendment is important when replacing Stage II engine with Stage III A engine. As Stage III A is no longer valid for new machines it still can be used for retrofitting, due to this directive. Stage III A engine complies the emission limit values of Stage II engine. Also type approval engineer from Sisu has confirmed that it's possible to use Stage III A engine in retrofit when replacing target is Stage II engine.

7.3. Approval of power unit

When specific engine with specific stage classification haven't been used in power unit before, the power unit needs approval before it can be used. To get approval engine manufacture has to apply certificate. The certificate is applied from testing institution. When the engine has certificate, Cargotec has to design basic modules to be used in the machine. Also electric and software designing must be done. Suppliers which provide emission control solutions have to develop specific solutions for our power unit. Development includes designing, simulation, moulds and testing of prototype. When the prototype of power unit is ready, application approval is needed. Bunch of different measurements have to be done to achieve application approval. The most common tests areas are listed in table 8. When all is ready power unit and a machine to where power unit is installed, needs product support and prototype follow-up.

Table 8. Approval tests

Cooling availability (engine, coolant, compressed air & transmission)
SCR –system
Temperature
Component vibration
Electric (voltage drop, starting, malfunctions)
Cold starting

7.4. CE marking & statement

CE (European Conformity) marking means that manufacture ensures that product, which has CE marking, confirms all EC directives and requirements. All new complete products brought to European Economic Area need CE marking. European Economic Area includes all EU member states in addition Norway, Liechtenstein and Iceland. CE marking was announced in year 1993 in directive 96/68/EEC. For retrofit engines CE marking is not needed due to machine is not brought to the market at the first time. Furthermore power units themselves don't need CE marking like all completely new machines do need. This has been confirmed by engineer manager Pasi Rantanen.

When retrofit is made for better emission classification, it will be necessary to provide Statement. The statement certifies that a new engine is accordant with specific emission classification. This statement is provided by Cargotec not by engine manufacture.

7.5. Container straddle carrier CSC

7.5.1 Frame, power unit, transmission and hydraulic pumps

For container straddle carrier a purpose was to replace old Sisu 74 ETA Stage II engine with Sisu Stage III B engine. But as explained earlier it was impossible without official approval. A possible engine is Sisu CTA 74 Stage III A. The first thing to do was to inspect if it's possible to use the old frame of power unit. The drawings of the old frame were compared with the drawings of the frame of power unit of the reference machine. Basically frames were same, they were both constructed from the same beams and therefore frame can be kept as the same. In addition the power unit installations of the Sisu ETA and Sisu CTA engines were the same. So CTA engine can be installed directly to the place of ETA engine. Istallation of radiator in ETA power unit was a bit different in comparison to radiator installation of CTA. Due to this the end plate of the frame has to be changed. Also there are a few brackets that need to be redesigned too. Designing a new drawing must be done and it would take approximately 25 working hours.

The old transmission can be used with the new CTA engine. Mechanical fastenings are same in CTA engine and in ETA engine. This has been inspected from the drawings of transmissions, from original transmission and transmission of CTA engine of reference machine. Another important matter to be checked was gear ratio. Gear ratios in original transmission and in transmission of CTA engine of reference machine were same. Table 9 shows the gear ratio.

Table 9. Gear ratios

Gear	Forward	Reverse
1	4.152	3.937
2	2.089	1.981
3	1.072	1.017

The old hydraulic pumps can be used also with the new engine. As hydraulic pumps are fastened to the transmissions and the transmissions are the same there is no need to change hydraulic pumps. Because the old hydraulic pumps are the same also original hydraulic break pumps can be left to their positions. Hydraulic brake pumps can also be left to their positions as the pumps are same in ETA engine and in CTA engine in reference machine. In addition fastenings of brake pumps were inspected and they were the same.

7.5.2 Electricity, programming and logic control

Because ETA engine is changed to CTA engine and both are in the end quite similar engines, the programming and logic control is much easier than in ESC machine. CPU of logic was kept as same as there was no need to change it. Also CAN card was left to be same. CAN communication had to be reprogrammed, because it needs to be at the same level with the new engine. Also there are a few more functions available concerning engine monitoring, e.g. fuel consumption and fault codes of engine. The fault codes are brought to the display in CTA engine in comparison in ETA engine they had to be read by using specific tool.

Due to CTA engine is much similar to ETA engine only electricity part what has to be changed is wiring harness. A new harness has to be designed and designing will take approximately 40 working hours. Changing the wiring harnesses, two pieces, will take estimated 40 working hours, including taking off the old ones and installation of new ones.

7.5.3 Other parts

Other parts of power unit and also a few parts of side frame had to be inspected. At the first parts have to be checked if they are the same in ETA power unit and in reference machine’s power unit. If they are not, then drawings have to be inspected if old parts are usable. Parts on the side frame that had to be inspected are shown in table 10, electric parts are not included in the table 10. The engine’s expansion tank (R, L) means both sides right and left. Always when engine retrofits are made, it’s good to change expansion tank. Change is made because expansion tank becomes harder due to sun light after years in service. If the expansion tank has been replaced some time ago it’s recommended that its hoses will be changed. Furthermore pipes and hoses have to be changed except hydraulic hoses.

Table 10. Parts of side frame to be inspected

Part	Act
Air filter installation N5863190	Usable
Engine expansion tank (R,L) N5862450, N5862460	To be changed to N5864390
Universal joint installation N5809830	Usable
Exhaust pipe assembly N5854500	Usable

All parts of power unit must be inspected. Table 11 shows the parts except engine installation parts, frame and its brackets. The radiator must be also checked, if it's possible to use old one. In this case using radiator had to be confirmed by engine supplier, we needed to be sure that it's okay to use the radiator with CTA engine. Correspond was that it's okay to use it. Also drawings of radiator installation had to be inspected to be sure that it really can be fastened to the CTA engine.

Fuel equipment has to be changed. The drawings have been inspected and the original fuel equipment for ETA engine is a bit different compared to the reference machine's CTA engine's fuel equipment. Hoses are different sizes but the connections to the fuel tank are the same and the tank doesn't need to be changed.

Table 11. Parts of power unit to be inspected

Part	Act
E & T Installation parts (R, L) N5844820, N5859210	Usable
Gearbox N5759030	Usable
Engine N5853420	To be changed to N5979890
Radiator installation N5853080	New design needed
Radiator + intercooler N5860150	Usable
Gear drain N5860390	Usable
Engine drain N5860510	Usable
Emptying of condenser water N5860550	Usable
Fuel equipment N5859220	To be changed N5933280
Oil filing of motor and transmission N5860520	Usable
Brackets for emergency stop button N5725710	Usable
Gearbox oil heater assembly N5888760	Usable
Sound insulation for propeller shaft N5800030	Usable
Bottom tray N5860560	Usable

7.6. Electric Straddle Carrier ESC

7.6.1 Frame, power unit & hydraulic pump

There were two possible engines to be used in retrofit. Sisu 98 ATI and another possible engine was Cummins QSL 9. The after-treatment solutions were different in both engines. In Cummins's engine there were used EGR system and diesel particulate filter, whereas in Sisu 98 ATI engine there is used SCR system. The engine for ESC was chosen to be Sisu 98 ATI because of after-treatment solution was used more in straddle carriers. Furthermore one significant reason was that Sisu 98 ATI installation is a bit easier and this influenced the choice. Also smaller engine manufactures are more flexible and adjustable than bigger manufactures. It is easier to work with them and it's possible to modify products for customer even with small volumes.

After the choice of engine the first thing to do was to inspect a frame of the power unit and the power unit installation. If it's not possible the use old frame for a new engine almost all parts need to be changed. The inspection was processed by comparing drawings from both frames (original machine and reference machine) and comparing drawings of power unit installation. The frame was decided to be changed because it wasn't able to be used the old frame for the new power unit. In this case the new frame can't be fastened to an original service platform of power unit. So the service platform needed to be changed too. For example engines are installed to frame vice versa and SCR system will take so much space that it's impossible to be fitted on the old frame. Design engineer Tapani Haikonen also confirmed that all new Stage III B engine installations are designed for a new platform, in which all fastening points are unified. This means that parts from the old power unit weren't able to be fitted to the new power unit.

Hydraulic equipment for upper frame needs modification, when hydraulic pump is changed. All the hoses coming from upper frame need to be refitted to the new hydraulic pump. In this case fortunately a new hydraulic pump has same qualities as the original pump has, meaning that all outputs, hydraulic volumes and pressures are same. Although the pump location changes from end of the engine to the side of the engine, as the original pump was driven by crankshaft whereas in Sisu 98 ATI engine the hydraulic pump is driven by power takeoff. Among others length and connections of hoses changes, and new drawings are needed. Design engineers need to design new drawings for hydraulics and hydraulic equipment for upper frame. Estimation for working time is approximately 40 hours.

7.6.2 Electricity, generator, programming & logic control

The original generator can be used with Sisu 98 ATI engine, this has been confirmed by research manager Mikko Nurmela. A few things must be taken care if generator is used as variable speed instead of single speed. An old power unit was a single speed machine, which means that engine is constantly running at 1800 rpm. A power output depends on a load of generator. An option was to select either single speed power unit or variable speed power unit. Variable speed means that engine runs between 1300 – 1800 rpm depending on power needed. Variable speed is more expensive due to technique it's achieved, however it also has lower fuel consumption. Notable is that engine needs specific parameters to be used either variable or single speed machine. The engine with correct parameters must be ordered from the supplier.

If variable speed engine is wanted by customer, from table 12 can be seen what needs to be done. There are what parts need to be changed and what work is to be done. Installation is a mechanical work. Also there might be a need for extra electric box for installation of rectifier and AUX-inverter that will create extra costs. Previous has to be checked if the retrofit will be processed in reality. An electric design contains drawing of a new wiring harness and updates for circuit diagram and a part list, estimate for updates is 30 working hours. Software programming is needed because engine's CAN communication is renewed. Power control parameters will be changed and logic modules need to be reprogrammed. If CAN card is changed engine CAN communication will be easier to program and it will take less time, around a day or two. Testing is needed because power output decreases about 80 - 90 kW in addition power control haven't been made earlier for original inverters of ECS machine. Everything has to be tested to be sure that there won't be any problems. Testing is made at the first in two weeks period there are also two one week periods later, depending on malfunctions. Follow-up means following-up about 2 days work in one month and it will last about six months, depending on how it has gone.

Table 12. Changes to variable speed power unit

Parts to be changes:	Work to be done:
Wiring harness	Installation of electric parts estimate 70 working hours
Rectifier	Electric design estimate 105 working hours
Fuses	Software programming estimate 120 hours
VSG AVR card	Software testing estimate 80 + 40 + 40 working hours + follow-up
AUX-inverter + Sin-filter T6 + transformer T5	
CPU	
Relays of fan and DEF	

Table 13 shows what parts, which to be changes if single speed system is selected. Electric design contains drawing of a new wiring harness and updates for circuit diagram and part list. Software programming means making of CAN communication. Testing will be done in two weeks and follow-up will continue as long as needed, six months top.

Table 13. Changes to single speed power unit

Parts to be changed:	Work to be done:
Wiring harness	Installation of electric parts estimate 60 working hours
Relays of fan and DEF	Electric design estimate 70 working hours
	Software programming, estimate 40 working hours
	Software testing estimate 80 working hours + follow up

7.6.3 Other parts

Due to reason that fuel equipments of engine are to be changed also connection to the fuel equipment of upper frame are to be modified. All other parts which are included in the power unit have to be changed. When the whole frame of power unit is changed and the engine manufacture is changed there usually are only a few parts that can be used in new engine. In this case only part is generator.

Estimate for mechanical installation of power unit is about 160 working hours, one assembler and one electrician, working time is two weeks. Mechanical installation has to be done by Cargotec's own employees.

7.7. Commission work

Commission work means tests that must be done always after engine retrofit has been finished. Tests are done after modification installation of new engines and purpose is to avoid future malfunctions. The new engines must be working and the performance must be equal to specification of engine. Performance is tested by performance recording tests, this is not available for SCS machine. Test will be done after power unit works as wanted. The performance record can be downloaded from the inverters of ESC. From the data can be seen a smoothness of acceleration and a smoothness of driving, e.g. over 2 km/h variation are not acceptable in smooth driving. Notable is that even though there are two engines in CSC, engines don't need synchronizing. PLC is able to read rpm from engine and transmission using sensors. In addition there is stall test for transmission. During test transmission needs to maintain its position with specific rpm. Last but not least Visco's fan has to be tested.

There are also stress test from where can be seen how engines temperatures rise during a few hours test. The test is performed with different level of loads and different time periods, to ensure that temperatures won't increase anymore than is necessary. Furthermore if something has been done badly usually stress test shows it, for example bad connections. A lifting speed is tested as well. When it comes to hydraulic, pressures of pumps must be checked and adjusted. For brake pumps maximum pressure has to be adjusted.

When any of electric parts have been changed, those will be tested also during commission work tests. Components themselves won’t be tested one by one. Purpose is to check that electricity works, alarms, fault codes, CAN-bus and engine rpm are under testing and connections are checked. For bus controlled engines after basic tests, engine must be tested with its own software, to ensure there are no errors in control unit. Reason is that some errors might occur to control unit but are not able to be seen from PLC. One of the most critical tests is emergency stop test. It’s a simple test but the engine must be able to be stopped.

All modifications to the programs must be checked during commission work tests. Furthermore alternator is tested and information to CPU must be arrived from the alternator. For ESC machine generator performance must be tested, at 1800 rpm output is 440 Vac.

Commission work tests will take approximately 3 - 4 days. Testers are one mechanic and one electrician. It takes about 2 - 3 working days to electricity tests and one day for driving tests. It must be noticed that if any problems occur, estimated four days can be drawn out to weeks. If any performance values like driving or lifting speeds are decreased, customer must be advised. Also if they want to modify for example driving speed it can be done during commission work tests. Working hours of machine are not to be touched. Customer must keep records when engines have been changed. An approval certificate from the customer is needed due to the engine warranty starts from that moment. Certificate confirms that engine retrofit is made appropriately and responsibility moves to the customer.

8 SUMMARY AND CONCLUSIONS

Engine retrofits are possible to be done from lower Stage classification to the higher without any legal problems anywhere in Europe. Some governments of European countries may support green values and give benefit for companies, which are trying to develop. Before the engine retrofits are planned must be taken care that a new power unit has an official approval. Most of modification packages are constructed from power units that already have an approval. The approval is only needed for complete new and unused power units. Furthermore it’s not possible to add for example SCR system to Stage III A engine for achieve Stage III B emission standards. All engines get one certificate and it can’t be updated anymore. To update Stage classification engine manufactures have to apply a new certificate for engine.

Inspections between an original and a new power unit must be done before retrofit. Frame, engine installation parts, transmission, generator, exhaust pipe, radiator, hydraulics, fuel equipment, expansion tank, bottom tray, hoses, electricity and software must be checked, if it’s possible to use original parts with a new engine. Have to be noticed that every new designed parts, usually raise the final price. Thus designing of new parts or installation may push a possible customer farther off. It may usually be easier to change the whole power unit to a new one with a new frame but it will raise the final price. Like in ESC the old generator can be used with new engine and it really is a significant part to keep when it comes to summing total price. There is a huge difference in selling totally new straddle carriers and selling modifications. Every euro counts in services business.

To achieve Stage III A classification like in Sisu CTA, engine is provided with common rail solution. The common rail adds high injection pressure, which atomizes fuel and lowers creation of particulate matter. Also in CTA the pistons are chosen to create PM as low as possible. In addition as in CTA engine there is used exhaust gas recirculation which lower nitrogen oxides emissions. Last but not least the electronic control unit has updated from EEM 2 to EEM 3. Total list of parts that need to be changed for CSC can be found from appendix 1.

To achieve Stage III B classification like in Sisu 98 ATI, engine has been equipped with high-pressure common rail, instead of regular direct injection system, and a new electronic control unit design EEM 4. Combustion process is optimized and fuel pressure is increased to 1800 bar. Selective catalytic reduction has been added, including AdBlue tank and pump system. The SCR system is the most significant reason to cut down exhaust emission. Also the SCR lowers operating costs of engine app. 10 % compared to Stage III A engines. Lower fuel consumption in comparison to Scania engine is achieved also by changing Scania single speed power unit to Sisu variable speed power unit. Furthermore the power take off have been added to Sisu 98 ATI engine. Total list of parts that need to be changed for ESC can be found from appendix 2.

Finally when retrofits are finished, engine manufacture needs prober proof that engines work so they can provide full warranty for engines. Proof can be for example records from commission work tests. Also the engine manufacturer can assign list of measurements that are needed to be done to achieve full warranty.

Duration of mechanical installation and commission work tests must be advised for the customer. Furthermore Cargotec needs to provide statement for customer, which proofs the correct Stage classification. All so updates for spare part and maintenance catalogues have to be given to the customer.

REFERENCES

W. Addy Majewski and Magdi K. Khair 2006. Diesel emissions and their control

Richard Stone 1992. Introduction to internal combustion engines

Klaus Mollenhauer and Helmut Tschöke 2010. Handbook of diesel engines

European Union directive 97/68/EC

European Union directive 2004/26/EC

European Union directive 96/68/EEC

Cargotec internal database

www.directindustry.com

www.openticle.com

www.dailytech.com

www.cummins.com

www.dieselnet.com

http://eur-lex.europa.eu/en/index.htm

APPENDICES

Appendix 1. Parts to be changed for CSC

CSC - Parts to be changed

Cargotec

Original part number	*Name*	*NET Qty*	*Unit*	*New part number*
NX-JAOS10-	* * * S I D E F R A M E * * *	1,0	Pcs	
N5862450	ENGINE EXPANSION TANK, LEFT	1,0	Pcs	N5864390
N5862460	ENGINE EXPANSION TANK, RIGHT	1,0	Pcs	N5864390
N5862670	WIRING HARNESS SISUDIESEL 74ETA	2,0	Pcs	Have to be design
NX-JAOS20-	* * * P O W E R U N I T * * *	1,0	Pcs	
N5786400	POWER UNIT FRAME N5786400A	2,0	Pcs	Have to be design
N5853420	ENGINE 74 ETA 60800 SISUDI	2,0	Pcs	N5979890
N5853080	RADIATOR INSTALLATION	2,0	Pcs	Have to be design
N5859220	FUEL EQUIPMENT	2,0	Pcs	N5933280
	* * * H O S E S * * *			
	* RADIATOR *			
N5759820	COOLING PIPE	1,0	Pcs	N5759820
N5876451	HOSE	1,0	Pcs	N5876451
N5876452	HOSE	1,0	pcs	N5876452
770573590	HOSE	2,0	pcs	770573590
68510306	HOSE	1,0	m	68510306
N5860160	TUBE	2,0	pcs	N5860160
N5693570	PIPE	2,0	pcs	N5693570
N5845020	TUBE	1,0	pcs	N5845020
N5853100	TUBE	1,0	pcs	N5853100
N5845040	TUBE	3,0	pcs	N5845040
N5845860	RUBBER HOSE	1,0	pcs	N5845860
	* COOLANT EMPTYING *			
KC65190300	HOSE	2,0	pcs	KC65190300
	* TRANSMISSION EMPTYING *			
KC65390500	HOSE	2,0	pcs	KC65390500
	* ENGINE EMPTYING *			
KC65100300	HOSE	2,0	pcs	KC65100300
	* OIL FILLING *			
KC65190900	HOSE	1,0	pcs	KC65190900

Original part number	Name	NET Qty	Unit	New part number
KC65190800	HOSE	1,0	pcs	KC65190800
KC65190700	HOSE	1,0	pcs	KC65190700
KC65190800	HOSE	1,0	pcs	KC65190800

Appendix 2. Parts to be changed for ESC

ESC - Parts to be changed

Cargotec

Original part number	*Part*	*NET Qty*	*Unit*	*New part number*
	* * * P O W E R U N I T * * *			
N5938800	FRAME,POWER UNIT	1,0	pcs	N6024090
N5938900	SERVICE PLATFORM FOR UPPER FRAME	1,0	pcs	N6024720
N5932170	INSTALLATION PARTS,ENGINE	1,0	pcs	N6026530
N5929350	ENGINE AGCO SISU POWER 98ATI-4V	1,0	pcs	JP106179
N5837730	RADIATOR,INSTALLATION, VISCO FAN	1,0	pcs	N6028030
N5899910	DRAIN,ENGINE OIL	1,0	pcs	N6025250
N5928720	EXHAUST PIPE INSTALLATION - > SCR	1,0	pcs	N6016480
N5842630	FUEL EQUIPMENT,POWER UNIT COMPARTMENT	1,0	pcs	N6025220
N5882630	AIR FILTER,INSTALLATION SISU 98 ATI	1,0	pcs	N6028090
N5928720	EXHAUST PIPE,INSTALLATION SCR EXHAUST	1,0	pcs	N6017810
N5899930	POWER UNIT,INSTALLATION	1,0	pcs	N6026940
N0304015H	HYDR.PUMP	1,0	pcs	JP106784
N5898160	HYDR. PUMP ASSEMBLE	1,0	pcs	Have to be design
-	HYDRAULICS,POWER UNIT	1,0	pcs	Have to be design
N5900000	COVERS,POWER UNIT COMPARTMENT	1,0	pcs	N6027500
N5904631	BOTTOM TRAY,INSTALLATION	1,0	pcs	N6024500
N5933150	FUEL EQUIPMENT,UPPER FRAME	1,0	pcs	Connections have to be changed
N5934361	HYDR. EQUIPMENT FOR UPPER FRAME	1,0	pcs	Have to be design
-	* * * POWER UNIT ELECTRIC EQUIPMENT * * *			
	* SINGLE SPEED *			
	WIRING HARNESS	1,0	pcs	N6027850
-	FISCO FAN AND ADBLUE FUSES	1,0	pcs	-
	* VARIABLE SPEED *			
-	WIRING HARNESS	1,0	pcs	N6027850
-	FISCO FAN AND ADBLUE FUSES	1,0	pcs	-
-	RECTIFIER	1,0	pcs	JP107581
-	FUSE	1,0	pcs	KS100044
-	FUSE	3,0	pcs	J022626
	CONTACT COVER	3,0	pcs	JP104719

Original part number	Part	NET Qty	Unit	New part number
-	COVER, FUSE	3,0	pcs	KS100046
-	CONTACT COVER	6,0	pcs	JP104718
-	ADAPTER	1,0	pcs	JP104573
-	ADAPTER	1,0	pcs	JP104574
-	RAIL	1,0	pcs	JP104575
-	COVERING PLATE	1,0	pcs	JP104576
-	RAIL	1,0	pcs	JP104577
-	PROFILE	1,0	pcs	JP104578
-	CONTACT COVER	1,0	pcs	JP104579
-	FUSE	3,0	pcs	JP106150
-	CONNECTION	1,0	pcs	JP107910
-	REGULATOR	1,0	pcs	JP104924
-	INVERTER	1,0	pcs	JP108460
-	SIGNAL FILTER	1,0	pcs	JP107291
-	TRANSFORMER	1,0	pcs	JP104123
-	EXTRA BOX	1,0	pcs	-
-	CPU UNIT	1,0	pcs	JP104415